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Improving Dynamic Range and Precision for Current-In-Plane Tunneling Measurements

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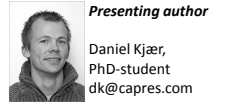
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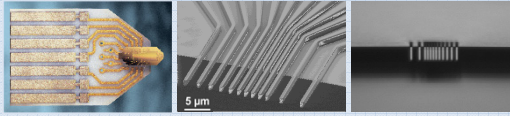
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Department of Micro- and Nanotechnology



Motivation

Improved dynamic range and measurement precision by implementation of position correction algorithms

Micro 12-Point Probe



Probe info

- Length: 10μm
- Width: 0.75μm
- Thickness: 1μm
- 8 subsets of 4 electrodes
 - Mean pitches: 1.5μm – 8.3μm
- Electrode material: Au

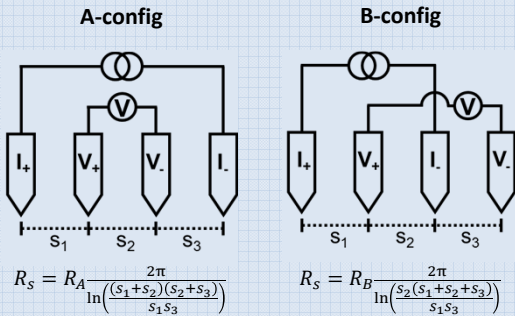
4-Point Measurements on a Single Sheet

- Apply fixed current
- Measure voltage
- Extract sheet resistance

$$R_S = \frac{V}{I} \frac{2\pi}{\ln\left(\frac{bc}{ad}\right)}$$

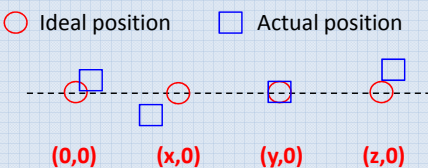
a = distance between I_+ and V_+
 b = distance between I_+ and V_-
 c = distance between V_+ and I_-
 d = distance between V_- and I_-

- Two independent 4-point configurations:



Positioning Errors

- Influences measured sheet resistance¹
- Two types of positioning errors:
 - Inline (first order effect)
 - Offline (second order effect)



Position Correction on a Single Sheet

Experimental

- A and B-config measurements
- Current: 200μA and 2000μA
- Frequency: 25Hz
- Integration time: 81ms
- Scan: 10x10 points, step size: 100μm
- Sample: 200mm wafer, 100nm Ru
- $R_S \approx 1.6\Omega/\text{sq}$

Positioning Error (inline)

- A-config: $\sigma_{R_A}^{rel} = \frac{\sqrt{5}}{2\ln(2)} \frac{\sigma_x}{s} \approx 1.613 \frac{\sigma_x}{s}$
- B-config: $\sigma_{R_B}^{rel} = \frac{4\sqrt{5}}{3\ln(3)} \frac{\sigma_x}{s} \approx 2.714 \frac{\sigma_x}{s}$
- $\sigma_x \approx 5\text{nm}$

Two Position Correction Strategies

- Modified van der Pauw²

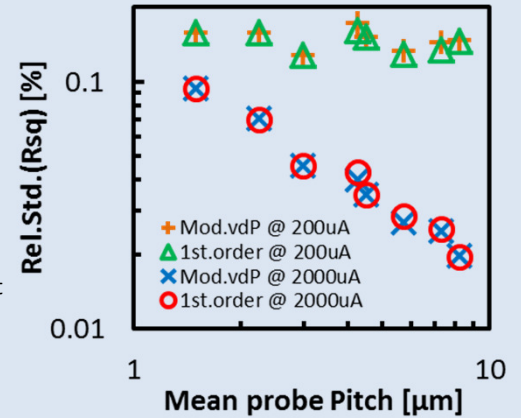
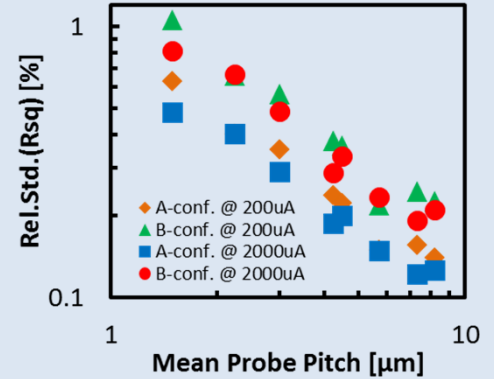
$$\exp\left(\frac{2\pi R_A}{R_S}\right) - \exp\left(\frac{2\pi R_B}{R_S}\right) = 1$$

- 1st. order approximation³

$$R_S = \frac{2\pi(R_A - \alpha R_B)}{\ln\left[\frac{y(z-x)}{x(z-y)}\right] - \alpha \ln\left[\frac{z(y-x)}{x(z-y)}\right]}$$

$$\text{where } \alpha = \frac{z(y-x)}{y(z-x)}$$

- Equal performance on a single sheet sample



Position Correction for CIPT Measurements on MTJs

$$\text{CIPT model}^4: R = \frac{V}{I} \frac{R_t R_b}{R_t + R_b} \frac{1}{2\pi(R_b)} \left\{ K_0\left(\frac{a}{\lambda}\right) + K_0\left(\frac{d}{\lambda}\right) - K_0\left(\frac{b}{\lambda}\right) - K_0\left(\frac{c}{\lambda}\right) + \ln\left(\frac{bc}{ad}\right) \right\}, \text{ where } \lambda = \sqrt{\frac{RA}{R_t + R_b}}$$

MC-simulations

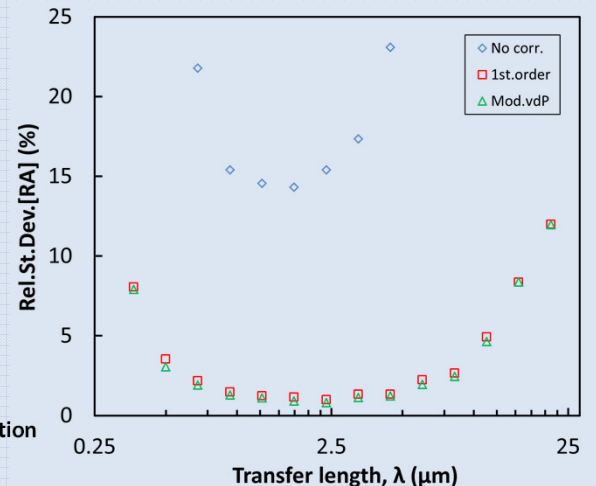
- $\sigma_x = 20\text{nm}$
- Electrical noise = 1%

Strategy (for each probe pitch):

- Measure A-B-A-B
- Calculate pseudo R_S
 - Mod.vdP
 - 1st. order approx.
- Theoretical pseudo R_S
 - Based on R_t , R_b and R_A
- Minimize error by fitting R_t , R_b and R_A

Conclusion:

Modified van der Pauw correction gives the best measurement precision and dynamic range



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